DTT magnet system

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on behalf of DTT team

ILO Industrial Opportunities Days

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Istituto Nazionale di Astrofisica - Capodimonte (Napoli)
Outline

- DTT magnet system overview
- Main procurements:
  - Superconducting and Copper strands
  - Coils conductors
  - Toroidal Field Coils
    - Winding pack
    - Casing
    - Integration
    - Testing
  - Central solenoid coil
  - Poloidal Field coils
Design requirements & constraints:

- Flexibility for plasma shaping
- 6 T on plasma @ 2.14 m radius
- Ripple < 0.5%
- Pulse length ~ 100 s
- Mature technology for schedule & budget constraints
Magnet system: overview

18 Toroidal Field coils
Nb$_3$Sn Cable-In-Conduit Conductors
5 Double-Pancakes (3 regular + 2 side)

6 Central Solenoid module coils
Nb$_3$Sn Cable-In-Conduit Conductors
6 independent modules

6 Poloidal Field coils
4 NbTi Cable-In-Conduit Conductors
2 Nb$_3$Sn Cable-In-Conduit Conductors
6 independent modules

Design based on proven and reliable technologies
Outline

- DTT magnet system overview
- **Main procurements:**
  - Superconducting and Copper strands
Superconducting & Copper Strands procurement

- Market survey notice issued on 21/12/2018
  (https://enea.ubuy.cineca.it/)
To set-up a list of qualified economic operators to be invited to a procedure

- Deadline for submission expression of interest on 22/01/2019

- Tender procedure (through negotiated procedure): invitation sent on 29/04/2019
  Most economically advantageous tender (MEAT) criterion adopted

- Deadline for presentation of offers: 27/05/2019

- Start of evaluations: 29/05/2019

- Completion of procedure and contract award expected within summer
Superconducting & Copper Strands procurement

The procurement has been divided in 4 lots:

1. Nb$_3$Sn (chromium coated) for TF:
   Hi-Grade performance at 4.2K: Ic (4.2K, 12T, 0.0% applied strain(*) ) > 285 A
   hysteresis losses < 1000 mJ/cm$^3$
   $L = 900 + n*900$
   55 tons for TFC
   < 38 weeks for first 3 tons form KoM

2. Nb$_3$Sn (chromium coated) for CS & PF1/6:
   Hi-Grade performance at 4.2K: Ic (4.2K, 12T, 0.0% applied strain(*) ) > 260 A
   hysteresis losses nts < 400 mJ/cm$^3$
   $L = 1050 + n*530$
   22 tons for CS & PF1/6
   < 35 weeks for first 2 tons from KoM

* ITER barrel measurement
3. **NbTi (nickel coated) for PF2/3/4/5:**

   Required Performance at 4.2K: \(I_c (4.2K, 5T) \geq 500 \text{ A}\)

   Hysteresis losses < 100 mJ/cm\(^3\)

   \[ L = 5000 + n\times10000 \]

   27.5 tons FOR PF2/3/4/5

   < 42 weeks for first 6 tons from KoM

4. **Cu (chromium coated) for TF, CS & PF1/6 and (nickel coated) for PF2/3/4/5:**

   0.82 ± 0.005 mm, Cr/Ni coating = 2 ± 1 µm

   \[ L = 5000 + n\times10000 \]

   RRR: > 300

   31 tons FOR TFC & CS & PF1/6 + 23 tons FOR PF

   < 26 weeks for first 7 tons from KoM
Outline

- DTT magnet system overview
- **Main procurements:**
  - Superconducting and Copper strands
  - *Coils conductors*
Conductors manufacturing will consist in:

- Cabling
- Jacketing & insertion
- Spooling
- Testing
- Shipping to coil manufacturers
- Tender launch in 08/19

**Key issues:**

- 316 LN jacket (samples and dummies to be provided in advance for winding test)
- 100% welds testing
- He leak testing (pressure, flow)
- Jacketing line ~ 880 m (for CS & PF)

**TF - ULs:**

54 rDP + 36 sDP + 8 spare

**PF - ULs:**

18 DP-PF1/6 + 1 spare + 16 DP-PF2/5 + 1 spare + 14 DP-PF3/4 + 1 spare

**CS - ULs:**

6 HF + 1 spare + 12 LF + 2 spare
TF Coils Conductors

TF Conductors manufacturing schedule:

- Cu dummies to be available 03/20
- First set of UL (including 1 superdummy) 06/20
- Production rate: 1 set/40 work. days

Main features:

- Unit length (UL): 240 m (regular), 170 m (lateral)
- Total # of ULs: 54 (regular) + 36 (lateral) + 8 spare
- Inner corner radius: 3.5 mm
- VF: 26.4%
- Nb3Sn strands: 504
- Cu segregated strands: 144
- Cabling pattern:
  \([(1Cu+2Nb3Sn)+(1Cu+2Nb3Sn)+3Nb3Sn]*3*4*6\]
- Wrapping: 0.05 mm thick, overlap 30%
# CS coils conductors

<table>
<thead>
<tr>
<th></th>
<th>CS- HF</th>
<th>CS- LF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating current (kA)</td>
<td>29.04</td>
<td>29.04</td>
</tr>
<tr>
<td>Supercon. Strands (0.82 mm)</td>
<td>648</td>
<td>180</td>
</tr>
<tr>
<td>Area no_Cu (mm²)</td>
<td>171.1</td>
<td>47.5</td>
</tr>
<tr>
<td>Cu strands (0.82 mm)</td>
<td>0</td>
<td>204</td>
</tr>
<tr>
<td>Area TOT. Cu (mm²)</td>
<td>171.1</td>
<td>155.2</td>
</tr>
<tr>
<td>Cable pattern</td>
<td>3 x 3 x 3 x 4 x 6</td>
<td>(2s.c.+1Cu)x3x(5+C1)x(6+C2); C1=3x3; C2=3x4x5</td>
</tr>
<tr>
<td>V.F. (%)</td>
<td>27</td>
<td>26</td>
</tr>
<tr>
<td>Jacket Thickness (mm)</td>
<td>4.1</td>
<td>2.0</td>
</tr>
<tr>
<td>Inner corner radius (mm)</td>
<td>4.1</td>
<td>2.0</td>
</tr>
</tbody>
</table>

**CS - ULs:**
- 6 HF + 1 spare
- 12 LF + 2 spare
# PF coils conductors

<table>
<thead>
<tr>
<th>Conductor</th>
<th>PF1/6</th>
<th>PF2/5</th>
<th>PF3/4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial Ext. Dim. (mm)</td>
<td>23.4</td>
<td>26.4</td>
<td>26.4</td>
</tr>
<tr>
<td>Vertical Ext. Dim. (mm)</td>
<td>28.2</td>
<td>27.7</td>
<td>27.7</td>
</tr>
<tr>
<td>Jacket thickness (mm)</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Inner Corner Radius (mm)</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Central Channel (OD/ID: mm)</td>
<td>7/5</td>
<td>7/5</td>
<td>7/5</td>
</tr>
<tr>
<td>Inter-turn insulation (mm)</td>
<td>1.8</td>
<td>1.8</td>
<td>1.8</td>
</tr>
<tr>
<td># SC strands (0.82mm, 1.9 Cu/noCu)</td>
<td>180 (Nb3Sn)</td>
<td>162 (NbTi)</td>
<td>324 (NbTi)</td>
</tr>
<tr>
<td># Cu strands (0.82mm, 1.9 Cu/noCu)</td>
<td>216</td>
<td>324</td>
<td>162</td>
</tr>
<tr>
<td>Total strand number</td>
<td>396</td>
<td>486</td>
<td>486</td>
</tr>
<tr>
<td>Void fraction</td>
<td>29.9%</td>
<td>31.9%</td>
<td>31.9%</td>
</tr>
<tr>
<td>Cable overlapping</td>
<td>0.1mm, 50%, SS</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**PF - ULs:**

- 18 DP-PF1/6 + 1 spare
- 16 DP-PF2/5 + 1 spare
- 14 DP-PF3/4 + 1 spare
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TF coils overview

18 **Toroidal Field coils**

**Nb$_3$Sn** Cable-In-Conduit Conductors

5 *Double-Pancakes* (3 regular + 2 side)

Double-Pancake winding **80 turns**

Max. hydraulic length: **110 m**

$I_{op}$: **44 kA**

$B_{max}$: **11.8 T**

$\Delta T_{margin} > 1.5$ K

**Mass 15 tons**

Jacket & Case material **316LN**
Manufacturing planning: TFC-01 (an example)
TF coils: qualification activities for WP

- Heat treatment (up to 650°C for ~ 2 weeks < 200 ppm O2 and other impurities)
- Insulation after heat treatment
- Internal joint (<2nOhm) to be tested in cryogenic conditions
- Vacuum pressure impregnation (VPI) ->
- Shear strength test of insulation
- High voltage DC tests in vacuum (Paschen proof) -> Vacuum chamber

~ 0.7 m of vertical displacement allowed (ε<0.1%)
**TF coils: casing**

**TF casing manufacturing schedule:**
- First delivery: 10/21
- Production rate: ~1 casing/months

~ 10 tons
Max thickness: ~ 90 mm
Support structures for PF included
Outer Intercoil structures included

**Key issues:**
- 316LN
- 100% welds control
- Dimensional controls with laser track
- Channels for cooling machined inside and sealed
- Jigs for composition and transport
- Mock-ups availability for coil integration in 09/20
TF coils: qualification activities for TF integration

- Welding process qualification record -> chamfer design
- WP insertion and embedding qualification
- Machining qualification and measurement (general medium tolerance class specified unless otherwise stated)
- Piping layout and welding process
- High voltage DC tests in vacuum (Paschen proof) for piping
**TF coils: testing**

**TF cryogenic testing in ENEA:**
- Commissioning 10/21
- First TF test in 06/22
- Test rate: ~2 month per TFC including coil preparation, cool-down (1 week), testing (1 week), warm-up, coil release

**Key issues:**
- High voltage DC tests in vacuum at Cryogenic
- 4.5 K, 6 bar, nominal current
- Quench test
- Insulation resistance test
- Joint resistance test (<2 nOhm)

*Courtesy of JT-60SA*
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CS coil overview

Requirements

- 6 independently fed modules;
- flux swing > 32.4 Weber;
- $R_{\text{max}} < 824 \text{ mm}$ innermost TF radius;
- Allow the future implementation of an additional insert coil (made of HTS)

Design choices (in current design_v22):

- $\text{Nb}_3\text{Sn}$ Cable-In-Conduit Conductors
- CICC $I_{\text{op}}$: 29.04 kA;
- $B_{\text{peak}}$: 13.2 T
- $R_{\text{min}} / R_{\text{max}}$: 443 mm / 755 mm
- Turns per module: 120 (HF) + 200 (LF)
- $DT_{\text{margin}} > 1.0 \text{ K}$

45 tons

5.3 m

1,5 m
CS coils: CS modules

CS module manufacturing schedule:

- First delivery (CS-00 for Cold test): 12/21
- Production rate: ~6 months/module

Coil height ~ 0,9 m
Coil inner diameter ~ 0,9 m
Coil outer diameter ~ 1,5 m
Mass ~ 7 tons

Turns HF 6 x 20
Turns LF 8 x 25

Cycling loading conditions (> 25000 cycles)

All dimensions at 4 K

CS1U/L: 797
CS2U/L & CS3U/L: 891

162.6
136
1 mm inter-grade insulation

Enea
Member of EUROfusion
**Key issues:**

- Layer wound solution with conductor grading (2 grades)
- Insulation before heat treatment (only glass)
- Embedded joints between layers
- Vacuum pressure impregnation
- High voltage DC tests in vacuum (Paschen proof)
- Tight tolerance on current line diameter and center axis
- Assembly to be performed after testing of each module in cryogenic conditions and full current

*All dimensions at 4 K*
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# PF coils overview

<table>
<thead>
<tr>
<th></th>
<th>PF1/6</th>
<th>PF2/5</th>
<th>PF3/4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iopmax [kA]</td>
<td>28.3</td>
<td>27.1</td>
<td>28.6</td>
</tr>
<tr>
<td>Bmax [T]</td>
<td>9.1</td>
<td>4.2</td>
<td>5.3</td>
</tr>
<tr>
<td>Turns (radial x vertical)</td>
<td>20 x 18</td>
<td>10 x 16</td>
<td>14 x 14</td>
</tr>
<tr>
<td>Dtmargin [K]</td>
<td>1.8</td>
<td>1.9</td>
<td>1.7</td>
</tr>
<tr>
<td>Mass [tons]</td>
<td>15</td>
<td>16</td>
<td>28</td>
</tr>
</tbody>
</table>
PF coils: PF winding

Most probably PF1/6 will be included in the procurement of CS

PF1/PF6:
- Coil height ~ 590 mm
- Inner diameter ~ 2,3 m
- Outer diameter ~ 3,4 m
- Mass ~ 20 tons
- Double pancakes 9

PF2/PF5:
- Coil height ~ 516 mm
- Inner diameter ~ 5,8 m
- Outer diameter ~ 6,4 m
- Mass ~ 20 tons
- Double pancakes 8

PF3/PF4:
- Coil height ~ 452 mm
- Inner diameter ~ 8,2 m
- Outer diameter ~ 9 m
- Mass ~ 33 tons
- Double pancakes 7

PF6 will be the first component to be tested and delivered
Concluding remarks

- From 2015 to 2018 the DTT roles and objectives have been fixed and a re-baseline has been provided
- From October 2018 the integrated design activity has started
- Strands procurements has been launched in spring 2019
- Major procurements for magnets will be launched shortly in fall 2019
- Conceptual design of ancillary components based on other tokamak experiences, design to be completed within 2020
- For further info & news look at:
  
  www.dtt-project.enea.it
  www.dtt-project.enea.it/downloads/DTT_IDR_2019_WEB.pdf
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  - *Feeders and current leads*
CTB for TF Coils

Feeders inside Cryostat (6 set)

Jumpers (1 set)

CTB for TF Coils

HTS-CL (KIT, 6 set)

In-Cryostat Piping

Valve Box (VB)

Transfer Line from He Refrigerator

Coil Terminal Box (CTB)

Feeders design completion within 2020

 Courtesy of JT-60SA

CTB for TF

Courtesy of JT-60SA
Feeders and Current Leads (CL)

6 CL for TFC in HTS
12 CL for PFC resistive
12 CL for CSC resistive

3 CL Boxes:
- PF with He dewar
- CS with He dewar
- TF